

APPENDIX P
THE SDA QUANTITATIVE RISK ASSESSMENT

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P.1 Introduction

In the Draft Environmental Impact Statement (Draft EIS), the New York State Energy Research and Development Authority's (NYSERDA's) preferred alternative for the State-Licensed Disposal Area (SDA) was to manage the facility in place for up to 30 more years. To meet its requirements under the State Environmental Quality Review Act (SEQR), NYSEDA tasked Dr. B. John Garrick to provide the analysis needed to assess the impacts from NYSEDA's preferred alternative for the SDA. Dr. Garrick, who is the current Chairperson of the U.S. Nuclear Waste Technical Review Board, and a former President of the Society for Risk Analysis, recommended the preparation of a quantitative risk assessment (QRA) for the SDA. At NYSEDA's request, Dr. Garrick assembled a team of highly qualified experts to prepare the QRA.¹

After considering public comments on the Draft EIS, NYSEDA is assessing whether the duration of in-place management can be reduced. If the time period is reduced to less than 30 years, the QRA, which addresses the impacts from a 30-year management period, will provide a conservative assessment of the integrated SDA risk from in-place management for that shorter time period.

A preliminary draft of the QRA report was made available for public review and comment in October 2008. In parallel, the QRA team also used their insights and results from the draft study (QRA 2008) to identify a number of technical issues that warranted more detailed examination and refinement. The 2009 version of the QRA benefits substantially from this evolution of the SDA risk assessment process. In particular, it accounts for the following enhancements of the 2008 models and supporting analyses.

- More comprehensive analyses of conditions that may cause water to enter the SDA trenches, and refinement of the corresponding trench water level probabilities.
- More comprehensive evaluation of NYSEDA programs for Buttermilk Creek water sampling to detect potential liquid activity releases.
- Improved quantification of uncertainties about radionuclide concentrations in the SDA trench soils and liquids.
- Improved correlations among regional weather data, incident precipitation, trench overflow fluid volumes, and flow rates in the adjacent streams.
- A sensitivity study that examines the potential risk impacts from postulated dramatic climate changes during the 30-year SDA operating period.
- Assessment of specific issues that were raised during public reviews of the 2008 draft study.

The Quantitative Risk Assessment for the State-Licensed Disposal Area (QRA 2009) evaluates the risk to the public from continued operation of the SDA for the next 30 years with its current physical and administrative controls. The QRA includes detailed models for the mobilization, transport, distribution, dilution, and deposition of released radioactive materials throughout the environment surrounding the SDA site, including

¹ The QRA preparation team includes Dr. B. J. Garrick, Study Director, John W. Stetkar, Principal Investigator, Andrew A. Dykes, Thomas E. Potter, and Stephen L. Wampler.

the integrated watershed formed by Erdman Brook, Franks Creek and Buttermilk Creek. Exposures to hazardous and toxic chemical impacts are not evaluated as part of the scope of this QRA. Hazardous and toxic chemical impacts are being evaluated as part of the Corrective Measure Study for the SDA being conducted under a RCRA Section 3008(h) Administrative Order on Consent.

This Appendix to the EIS contains a summary of the 2009 QRA for the SDA; the entire QRA report, including supporting models, data, and analyses is available as a separate document from NYSERDA.²

P.2 The QRA Framework

The fundamental elements of the QRA process are (1) the “triplet” definition of risk (defined below) to serve as a general framework for the meaning of risk, (2) a scenario approach that clearly links initial (*initiating events or initial conditions*) and final states (*consequences*) with well defined intervening events and processes, (3) the representation of uncertainty by a probability distribution (*the probability of frequency concept*), (4) a definition of probability that measures the *credibility* of a hypothesis based on the supporting evidence, and (5) information processing rooted in the fundamental rules of logic.

The general framework for the QRA is the “set of triplets” definition of risk.

$$R = \{ \langle S_i, L_i, X_i \rangle \}_c,$$

In this format, the brackets denote “the set of,” and the subscript c implies that the set is complete. The risk (“R”) is a comprehensive answer to the following questions:

- “What can go wrong?” This question is answered by describing a structured, organized, and complete set of possible damage scenarios (“S”).
- “What is the likelihood of each scenario?” This question is answered by performing detailed analyses of each risk scenario, using the best available data and engineering knowledge of the relevant processes, and explicitly accounting for all sources of uncertainty that contribute to the scenario likelihood (“L”).
- “What are the consequences?” This question is answered by systematically describing the possible end states for each risk scenario, such as different radiation dose levels that may be received by a member of the public (“X”).

P.3 The QRA Scope

This study evaluates the risk from continued operation of the SDA for the next 30 years with its current physical and administrative controls. The scope of this risk assessment is limited to quantification of the radiation dose received by a member of the public, represented by two potential receptors.

- A permanent resident farmer located near the confluence of Buttermilk Creek and Cattaraugus Creek
- A transient recreational hiker / hunter who traverses areas along Buttermilk Creek and the lower reaches of Franks Creek

² The complete QRA report (revised August 2009) is available on the Internet at <http://www.nyserda.org/publications/sdaqquantitativriskassessment2009.pdf>. Copies on CD can be requested from NYSERDA at END@nyserda.org, or by calling Elaine DeGiglio at (716) 942-9960, extension 2423.

The study evaluates potential releases of liquid, solid, and gaseous radioactive materials from the 14 waste trenches at the SDA site. It examines a broad spectrum of potential natural and human-caused conditions that may directly cause or contribute to these releases. Threats to the site are grouped into two general categories.

- **Disruptive Events** are unexpected events that cause an immediate change to the site. They are typically characterized by an event occurrence frequency and by directly measurable immediate consequences. Examples are severe storms, tornadoes, earthquakes, fires, and airplane crashes.
- **Nominal Events and Processes** are expected events and natural processes that evolve continuously over the life of the facility. They are typically characterized by a rate, which may be constant or changing over time. The potential consequences from these processes depend on the duration of the exposure period. Examples are groundwater flows, slope subsidence, and the aging of engineered and natural systems.

The QRA includes detailed models for the mobilization, transport, distribution, dilution, and deposition of released radioactive materials throughout the environment surrounding the SDA site, including the integrated watershed formed by Erdman Brook, Franks Creek, and Buttermilk Creek.

This study does not present a quantitative evaluation of the risk from intentional acts of destruction, war, terrorism, or sabotage. Current risk assessment practices for most sensitive facilities in the United States, including nuclear power plants, do not include a quantitative analysis of the risk from these types of threats. Quantifying these risks would require the systematic evaluation of detailed threat scenarios for these sensitive facilities, which would present significant security concerns. While a quantitative assessment of the risk from acts of terrorism on the SDA was not developed for this study, the QRA team did perform limited qualitative and simplified analyses of such threats to provide some insights on this issue (see Section 15.2 of the complete QRA report referenced earlier).

Exposures to hazardous and toxic chemical impacts are not evaluated as part of the scope of this QRA. Hazardous and toxic chemical impacts are being evaluated as part of the Corrective Measure Study for the SDA being conducted under a RCRA Section 3008 (h) Administrative Order on Consent.

P.4 Evaluated Threats

The scope of potential threats considered in this study includes a broad variety of natural phenomena and processes, and human-caused events. Systematic methods were used to examine and screen identified threats for their potential significance to the SDA risk. Table P-1 lists the threats that were retained for explicit evaluation in the QRA models. Table P-2 lists the threats that were evaluated and eliminated from further detailed analysis.

P.5 Release Mechanisms and Scenarios

Five release mechanisms were defined to provide a framework and context for the risk scenarios. Each scenario begins with an initiating disruptive event or an evolving site process, and it results in a release of radioactive materials into the external environment. It then continues through the mobilization and transport elements of the risk models, where the released materials are distributed, diluted, and deposited throughout the area surrounding the site. The scenario finally terminates in a source of radiation exposure and dose to the study receptors.

The five SDA release mechanisms are:

- **Release Mechanism 1** involves liquid releases from the waste trenches via groundwater flows through the Unweathered Lavery Till (ULT) and Kent Recessional Sequence (KRS) soil layers. Four risk scenarios were evaluated for this release mechanism.
- **Release Mechanism 2** involves liquid releases from the waste trenches via groundwater flows through the Weathered Lavery Till (WLT) soil layer. One risk scenario was evaluated for this release mechanism.
- **Release Mechanism 3** involves liquid overflows of the waste trenches and releases via surface water runoff. Nine risk scenarios were evaluated for this release mechanism.
- **Release Mechanism 4** involves physical breaches of the waste trenches and releases of liquid and solid radioactive materials. Sixteen risk scenarios were evaluated for this release mechanism.
- **Release Mechanism 5** involves extensive physical disruption of the SDA site and airborne releases from the waste trenches. One risk scenario was evaluated for this release mechanism.

The release mechanisms and scenarios evaluated are listed in Table P-3.

P.6 Supporting Analyses

Detailed analyses were performed to quantify the frequencies of all threats that are analyzed in the QRA models. In most cases, extensive effort was required to supplement the limited available information and data from previous assessments, to perform a realistic evaluation of the threat frequencies and their associated uncertainties.

Several “fragility analyses” were performed to quantify the conditional likelihood that a disruptive event or natural process will cause a release of radioactive materials from the SDA waste trenches. Members of NYSERDA’s Independent Expert Review Team (IERT), for which Dr. Garrick was the chairman, provided technical guidance and input for a number of these analyses, developed some of the analytical models, and performed some of the detailed quantifications. The fragility analyses evaluated the following technical issues:

- Seismic failures of the slopes adjacent to the SDA site
- Failures of the slopes due to landslides that are not related to seismic events or erosion
- Erosion of the waste trench caps
- Erosion and migration of slope gullies
- Groundwater flows through lateral and vertical release pathways
- Trench filling and overflows from water intrusion

NYSERDA engineers provided evaluations of potential intervention efforts to stop or mitigate the consequences of specific radioactive material release scenarios. Analyses were also performed to quantify the effects from conditions that may require extensive repairs or replacement of the geomembranes.

Comprehensive inventories of the SDA waste materials were compiled from existing databases, including the distribution of specific radionuclides at 50-foot intervals in each trench. This information was used to quantify the physical form, quantity, and radioisotopic content of the materials that are released during each risk scenario.

Geohydrologic models were developed for the area surrounding the SDA site, including the integrated drainage basin for Erdman Brook, Franks Creek, and Buttermilk Creek. These models were used to quantify flows and dilution of radioactive liquids that are released into the stream systems, the transport of solids, and the deposition of contaminated material in stream bed sediments. An atmospheric dispersion model was used to quantify flows, transport, and dilution of radioactive aerosols released into the air.

Analyses were performed to evaluate the exposure of each receptor to contaminants that are released during each risk scenario, accounting for the specific form of the material (e.g., liquid, solid, or airborne), its quantity and concentration at the point of exposure, and its radioisotopic content. Potential doses accrue from direct exposure to contaminated creek water, sediments, and airborne species. The analyses also assume that creek water is used for crop irrigation and livestock water supplies, resulting in additional potential doses through these food chain pathways. It is assumed that creek water is not used as a domestic potable water supply. The total effective dose equivalent (TEDE) for each receptor is quantified in terms of millirem (mrem) accumulated in a 1-year period, for comparison with public health standards and other sources of radiation risk.

The QRA contains a sensitivity study that examines the potential risk impacts from postulated dramatic climate changes during the 30-year SDA operating period. The sensitivity analyses account for increased frequencies of severe high winds, tornadoes and precipitation. In particular, the analyses evaluate the effects from postulated conditions that would apply at the site if all meteorological parameters were assumed to persist at the 95th percentiles of their current uncertainty ranges throughout the next 30 years. While these extreme meteorological conditions are not expected to evolve over the 30-year duration of this risk study (based on existing climate data), if the conditions were to occur, the effect would be an increase in the risk over the baseline by a factor of only 2.3. Thus, the sensitivity study confirmed that a release which results in a dose of 100 mrem in 1 year, or more, to an offsite receptor remains very unlikely during the next 30 years of SDA operation.

P.7 The SDA Risk

Figure P-1 shows the integrated risk curves for the SDA site in the “frequency of exceedance” format that is typically used to display QRA results. The following examples illustrate how these curves are interpreted.

Frequency of Dose Exceeding 0.1 mrem in 1 Year

This result is obtained by taking a vertical “slice” through Figure P-1 at the dose value of 1.0E-01 mrem in 1 year. Figure P-2 shows that “slice,” in the “probability density” format that displays the calculated uncertainty about the frequency of this dose level.

The mean total frequency of all threats that cause radioactive material releases from the SDA site which result in a total effective dose to all receptors of 0.1 mrem in 1 year, or more, is approximately 7.0E-03 event per year (i.e., one event in 145 years). There is equal probability that the release frequency for this dose is greater than, or less than, the median value of approximately 6.6E-03 event per year (i.e., one event in 150 years). The range of values between the 5th probability percentile and the 95th probability percentile in Figure P-1 is the “90% confidence interval” of the uncertainty about the risk. This means that there is 90% probability that the release frequency for a particular dose level is within this interval. There is 5% probability that the release frequency is less than the lower end of the 90% confidence interval (i.e., lower than the 5th probability percentile), and there is 5% probability that the release frequency is higher than the upper end of the interval

(i.e., higher than the 95th probability percentile). For the 0.1-mrem dose “slice” shown in Figure P–2, the QRA authors are 90% confident that the release frequency is between $6.4\text{E-}03$ event per year and $7.8\text{E-}03$ event per year (i.e., between one event in 155 years and one event in 130 years). Since the mean value is the “expected” frequency of these releases, the QRA authors do not “expect” to have a release that results in a dose of 0.1 mrem in 1 year, or more, during the next 30 years of SDA operation. However, a complete accounting for the uncertainty in the risk curves concludes that there is approximately a 1% probability that this type of release may occur during the next 30-year operating period.

Frequency of Dose Exceeding 100 mrem in 1 Year

This result is similarly obtained by taking a vertical “slice” through Figure P–1 at the dose value of $1.0\text{E+}02$ mrem in 1 year. Figure P–3 shows that “slice”.

The mean total frequency of all threats that cause radioactive material releases from the SDA site which result in a total effective dose to all receptors of 100 mrem in 1 year, or more, is approximately $5.1\text{E-}04$ event per year (i.e., one event in 2,000 years). There is equal probability that the release frequency for this dose is greater than, or less than, the median value of approximately $4.8\text{E-}04$ event per year (i.e., one event in 2,100 years). The QRA authors are 90% confident that the release frequency is between $3.9\text{E-}04$ event per year and $6.4\text{E-}04$ event per year (i.e., between one event in 2,600 years and one event in 1,600 years). The QRA results confirm that a release which results in a dose of 100 mrem in 1 year, or more, is extremely unlikely during the next 30 years of SDA operation.

Figure P–4 is another representation of the SDA risk results, with an expanded scale that focuses on the dose range from 10 to 1000 mrem in 1 year. It displays the risk in terms of the number of release events that occur during the SDA 30-year operating period that is covered by this study. It is obtained by multiplying the frequency scale in Figure P–1 by 30 years. The maximum value of the y-axis corresponds to 1 event that results in a release of radioactive material from the SDA during the next 30 years. Figure P–5 shows the uncertainty distribution for the “slice” at the 100 mrem dose level. These results clearly show that it is very unlikely that a release will occur during the next 30 years with the consequences of a 1-year dose of 100 mrem, or more. For example, the 95th probability percentile in Figure P–4 at the 100-mrem vertical “slice” is a factor of approximately 50 times lower than the once-in-30-year release value. This means that the QRA authors are 95% confident that this type of release will occur much less often than once in 30 years. Figure P–5 shows the complete uncertainty distribution for the “slice” at the 100 mrem dose level, further confirming the very high confidence in this conclusion.

Table P–4 lists the mean (“expected”) frequency of radioactive material releases for each risk scenario in terms of release events per year, the corresponding mean consequences from that scenario in terms of equivalent mrem dose in 1 year to all exposed receptors, and the product of the scenario frequency and consequences. This tabulation is useful to understand the detailed contributors to the overall SDA risk and their relative importance.

Only nine scenarios individually account for more than 1% of the total SDA risk, and these nine scenarios collectively account for almost 99% of the total. Each of the remaining 22 scenarios contributes less than 1% of the overall risk, and the 22 scenarios collectively account for just slightly more than 1% of the total. The top six scenarios for total SDA risk are:

- **Scenario 1 – 2** is the second scenario defined for Release Mechanism 1. It accounts for approximately 30% of the total SDA risk. The scenario involves lateral groundwater flows through the ULT soil layer. These releases occur when water levels in the waste trenches are at or near the interface between the ULT and WLT soil layers.

- **Scenario 4 – 1c** involves physical breaches of the waste trenches nearest to the East side and North end of the SDA. It accounts for approximately 23% of the total SDA risk. The trench breaches are caused by localized landslides or seismic events that destabilize the adjacent slopes. Scenario 4 – 1c evaluates the doses from liquid releases that occur when water levels in the waste trenches are at their current elevations, or lower.
- **Scenario 4 – 1** is similar to Scenario 4 – 1c. It also involves physical breaches of the waste trenches nearest to the East side and North end of the SDA that are caused by localized landslides or seismic events. It accounts for approximately 12% of the total SDA risk. Scenario 4 – 1 evaluates the doses from contaminated solids that are released from the damaged trenches.
- **Scenario 2 – 1** is the only scenario for Release Mechanism 2. It accounts for approximately 10% of the total SDA risk. The scenario involves lateral groundwater flows through the WLT soil layer near the surface of the SDA site. These releases can occur only when the water levels in the waste trenches are high, and the trenches are nearly full of water.
- **Scenario 1 – 3** is the third scenario defined for Release Mechanism 1. It accounts for approximately 7% of the total SDA risk. The scenario involves lateral groundwater flows through the ULT soil layer. These releases occur when water levels in the waste trenches are at their current elevations.
- **Scenario 3 – 4** is the fourth scenario defined for Release Mechanism 3. It accounts for approximately 6% of the total SDA risk. The scenario involves initial site conditions when the geomembranes are not intact, and the trench compacted clay caps are in their normal state. Water levels in the waste trenches are at or near the interface between the ULT and WLT soil layers. Total precipitation during a 14-day period exceeds 9 inches, including at least one storm with rainfall intensity that is severe enough to erode the trench caps and allow water intrusion to fill the trenches. The trenches overflow, and contaminated liquid enters the adjacent streams through surface runoff.

Table P-4 shows that seismic damage, gully erosion, and landslide scenarios in Release Mechanism 4 contribute increasingly to the “low frequency / high consequence” end of the risk profile in Figure P-1. The table shows that the mean doses from some of these scenarios can be quite significant. However, the release frequencies are extremely small, resulting in negligible contributions to overall site risk. “Intermediate frequency / intermediate consequence” scenarios in Release Mechanism 3 also contribute to the middle range of the risk spectrum.

The approximate fractional risk contribution from each major release mechanism is:

Release Mechanism 1: Groundwater flows through the ULT	45%
Release Mechanism 2: Groundwater flows through the WLT	10%
Release Mechanism 3: Trench overflows and surface water runoff	9%
Release Mechanism 4: Trench breaches by erosion, landslides, and earthquakes	36%
Release Mechanism 5: Airborne releases from SDA physical impacts	<< 0.1%

P.8 Conclusions

The QRA results confirm that the public health risk from operating the SDA for the next 30 years is well below widely applied radiation dose limits, such as the 100 mrem per year limit specified under “Radiation Dose Limits for Individual Members of the Public” in Part 380 of the State of New York Codes, Rules, and Regulations (6 NYCRR Part 380) and in Part 20 of Title 10 of the Code of Federal Regulations (10 CFR 20).

There is extremely high confidence that potential releases of radioactive materials from the SDA which may result in a 1-year dose to any member of the public of 100 mrem, or more, will occur much less often than once in 30 years.

These results should not be interpreted to mean that a release of this magnitude is impossible. They simply indicate that a release with these consequences is extremely unlikely during the next 30 years. If the SDA site could be maintained in its current state in perpetuity (including all geohydrologic and meteorological conditions) it would be expected that this type of event would occur only once in approximately 2,000 years.

This low level of risk will be maintained only if NYSERDA continues to operate the SDA according to its current physical and administrative controls.

The quantified risk from the SDA is dominated by a small number of event scenarios. A total of nine scenarios accounts for almost 99 percent of the overall risk. Five of these scenarios involve releases of radioactive liquids from the waste trenches through groundwater flow paths. Two scenarios involve trench overtopping and radioactive liquid releases via surface runoff during heavy precipitation that occurs while the geomembranes are not intact. Two scenarios are caused by localized landslides or seismic events that result in partial breaching of waste trenches near the site boundaries, with subsequent releases of contaminated solids and liquids.

There is very large uncertainty about several of the most important risk contributors identified in this study. The three most significant sources of uncertainty are:

- Models and analyses for the groundwater release pathways. Substantial reduction of these uncertainties may be achieved by extensive refinements to the groundwater flow models, supporting data, and analyses.
- Estimation of radionuclide concentrations in the trench leachate. These uncertainties may be reduced by further refinements to the QRA evaluations of the distribution coefficients for liquid concentrations of the most risk-sensitive radionuclides. Additional sampling of the trench leachate may also reduce these uncertainties. However, each trench contains a small number of sample points, and large variability has been observed in previously measured nuclide concentrations. Therefore, limited benefit may be realized from additional sampling with the sole purpose to reduce uncertainties in the estimated average nuclide concentrations in the trench leachate. Nonetheless, consideration of periodic monitoring of trench leachate concentrations for this and other purposes, such as assessment of trench water turnover rates, may be warranted.
- Evaluation of SDA slope stabilities and non-seismic slope failures. It is likely that these uncertainties can be reduced through further refinements to the slope failure models and the trench intersection probabilities.

The first two sources of uncertainty have compound effects for the liquid release scenarios in Release Mechanisms 1 and 2. The second source of uncertainty also affects all other liquid release scenarios. The third source of uncertainty affects the most important risk contributors from Release Mechanism 4. Relatively small reductions in the uncertainties may have a rather significant impact on the quantified risk, due to the numerical effects from low probability “tails” of the uncertainty distributions.

P.9 Recommendations

Apart from decisions regarding possible refinements to the QRA models, data, and analyses, it is recommended that NYSERDA:

- Continue to actively maintain trench water levels below the ULT / WLT interface level, regardless of the status of the geomembranes and other activities at the site.
- Minimize the amount of time that the geomembrane covers are not intact, and the surface of the trench caps is exposed. This includes expedited repairs or replacement of damaged geomembrane sections, and minimizing the time and extent of surface uncovering during planned geomembrane replacements.
- Formalize emergency preparedness plans and guidelines for responses to the types of release scenarios that are evaluated in this study. The risk from specific scenarios is affected significantly by the credit that has been applied for these intervention and mitigation responses.
- Consider the benefits from a program to periodically sample the water in each trench and monitor the concentrations of radionuclide species.

Table P-1 Threats Included in the SDA Risk Assessment

Disruptive Events

- Aircraft Crashes
 - Commercial
 - General aviation
 - Military
- Erosion
 - Local streams
 - Trenches
- Extraterrestrial Impacts (meteorites)
- Fires
 - Offsite (e.g., grass fires, forest fires)
- Flooding Events
 - Extreme precipitation
 - Rapid snow melt
- High Wind Events
 - Extreme sustained winds
 - Wind gusts
 - Tornadoes
- Landslides
- Pipeline Accidents
 - Site natural gas supply pipe
- Seismic Events
 - Direct seismic failures
- Severe Storms (snow)

Nominal Events and Processes

- Corrosion / Deterioration / Decomposition
 - Geomembrane covers
 - Crates, boxes
 - Steel drums
- Groundwater Intrusion
 - Historic intrusion
 - Rapid intrusion (“bath-tubbing”)
- Soil Shrink / Swell / Consolidation

Table P-2 Potential SDA Threats that were Evaluated and Eliminated from further Detailed Analysis

<ul style="list-style-type: none">• Avalanches• Biological Events• Drought• Erosion<ul style="list-style-type: none">- Coastal/lake shore erosion- River bank erosion• Excavation of Contaminated Stream Sediments• Explosions• Extraterrestrial Impacts (involving meteorites greater than 1 meter in diameter)• Extreme Temperatures (heat, cold)• Fires<ul style="list-style-type: none">- Onsite facilities (“internal fires”)• Flooding Events<ul style="list-style-type: none">- Onsite facilities (“internal flooding”)- Dam failure- Site water supply pipe failure- Seiche- Storm surge- Tsunami• Fog• Frost• High Tides• Hurricanes• Ice Cover• Lightning• Loss of External Power Supplies• Low Lake or River Water Level• Nearby Facility Accidents<ul style="list-style-type: none">- Industrial- Chemical- Military• NRC-Licensed Facility Decommissioning Activities<ul style="list-style-type: none">- Direct accident impacts on SDA- Effects on site grading, surface water runoff, erosion• Radiolytic/Chemical Interactions• River Diversion• Seismic Events<ul style="list-style-type: none">- Seismic-induced fires- Seismic-induced flooding (e.g., piping failures)
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- Severe Storms
 - Hail
 - Sand storms
 - Dust storms
- Sinkholes
- Site Intrusions (direct intrusion into the SDA during the 30-year period of this study)
- Toxic Gas Releases
- Transportation Accidents
 - Rail
 - Highway
 - Shipping (by navigable waterway)
- Volcanic Activity

Table P-3 Release Mechanisms and Scenarios

<i>Release Mechanism</i>	<i>Scenario</i>	<i>Threat Condition – Damage Scenario</i>
<p style="text-align: center;">1 Liquid Releases from Waste Trenches via Groundwater through the Unweathered Lavery Till (ULT) and Kent Recessional Sequence (KRS) Soil Layers</p>	1 – 1	Initial trench water level high; Lateral flow through ULT; NYSERDA detection via stream water sampling; NYSERDA mitigation
	1 – 2	Initial trench water level at the WLT/ULT interface; Lateral flow through ULT; NYSERDA detection via stream water sampling; NYSERDA mitigation
	1 – 3	Initial trench water at the current level; Lateral flow through ULT; NYSERDA detection via stream water sampling; NYSERDA mitigation
	1 – 4	Vertical flow through ULT and lateral flow through KRS; All trench water levels; NYSERDA detection via Buttermilk Creek sediment sampling; External intervention to limit receptor exposure
<p style="text-align: center;">2 Liquid Releases from Waste Trenches via Groundwater through the Weathered Lavery Till (WLT) Soil Layer</p>	2 – 1	Initial trench water level high; Lateral flow through WLT; NYSERDA detection via stream water sampling; NYSERDA mitigation
<p style="text-align: center;">3 Liquid Overflows of the Waste Trenches and Releases via Surface Water Runoff</p>	3 – 1	Initial trench water level high; Geomembranes unavailable; Trench caps intact; Severe precipitation (24- or 48-hour precipitation event) erodes caps
	3 – 2	Initial trench water level high; Geomembranes initially in place; Trench caps intact; Severe storm destroys geomembranes and erodes caps
	3 – 3	Initial trench water level high; Geomembranes damaged; Trench caps disrupted; Precipitation ≥ 1 inch in 14 days
	3 – 4	Initial trench water level at the WLT/ULT interface; Geomembranes unavailable; Trench caps intact; Precipitation ≥ 9 inches in 14 days (assumed to erode caps)
	3 – 5	Initial trench water level at the WLT/ULT interface; Geomembranes intact; Trench caps intact; Severe storm (Wind or Tornado) destroys geomembranes and erodes caps; Precipitation ≥ 9 inches total accumulation in 14 days
	3 – 6	Initial trench water level at the WLT/ULT interface; Geomembranes unavailable; Trench caps disrupted; Precipitation ≥ 9 inches in 14 days
	3 – 7	Initial trench water at the current level or lower; Geomembranes unavailable; Trench caps intact; Precipitation ≥ 25 inches in 14 days (assumed to erode caps)
	3 – 8	Initial trench water at the current level or lower; Geomembranes initially in place; Trench caps intact; Severe storm (Wind or Tornado) destroys geomembranes and erodes caps; Precipitation ≥ 25 inches accumulation in 14 days
	3 – 9	Initial trench water at the current level or lower; Geomembranes unavailable; Trench caps disrupted; Precipitation ≥ 25 inches in 14 days

<i>Release Mechanism</i>	<i>Scenario</i>	<i>Threat Condition – Damage Scenario</i>
4 Physical Breaches of the Waste Trenches and Releases of Liquid and Solid Radioactive Material	4 – 1	Localized landslide or seismic-induced slope failure Damage Condition 1 ^a ; Solid releases
	4 – 1a	Initial trench water level high; Localized landslide or seismic-induced slope failure Damage Condition 1; Liquid releases
	4 – 1b	Initial trench water level at the WLT/ULT interface; Localized landslide or seismic-induced slope failure Damage Condition 1; Liquid releases
	4 – 1c	Initial trench water at current level or lower; Localized landslide or seismic-induced slope failure Damage Condition 1; Liquid releases
	4 – 2	Geomembranes unavailable; Gully erosion; Solid releases
	4 – 2a	Initial trench water level high; Geomembranes unavailable; Gully erosion; Liquid releases
	4 – 2b	Initial trench water level at the WLT/ULT interface; Geomembranes unavailable; Gully erosion; Liquid releases
	4 – 2c	Initial trench water at current level or lower; Geomembranes unavailable; Gully erosion; Liquid releases
	4 – 3	Seismic – induced slope failure Damage Condition 2 ^b ; Solid releases
	4 – 3a	Initial trench water level high; Seismic-induced slope failure Damage Condition 2; Liquid releases
	4 – 3b	Initial trench water level at the WLT/ULT interface; Seismic-induced slope failure Damage Condition 2; Liquid releases
	4 – 3c	Initial trench water at the current level or lower; Seismic-induced slope failure Damage Condition 2; Liquid releases
	4 – 4	Regional/Global landslide; Solid releases
	4 – 4a	Initial trench water level high; Regional/Global landslide; Liquid releases
	4 – 4b	Initial trench water level at the WLT/ULT interface; Regional/Global landslide; Liquid releases
4 – 4c	Initial trench water at current level or lower; Regional/Global landslide; Liquid releases	
5 Extensive Physical Disruption of the SDA Site and Airborne Releases from the Waste Trenches	5 – 1	Aircraft crash or meteorite; Geomembranes damaged and surface disturbed; Airborne releases

^a Damage Condition 1 – Slope failures intersect Trenches 1/2, Trench 8 and 125 feet of the north ends of Trenches 3, 4 and 5.

^b Damage Condition 2 – Slope failures intersect Trenches 1/2, Trench 3, 8 and 9, and 250 feet of the north ends of Trenches 4 and 5.

Table P-4 SDA Risk Scenarios

<i>Scenario</i>	<i>Mean Frequency (event / year)</i>	<i>Mean Dose (mrem in 1 year)</i>	<i>Mean Frequency x Dose [(mrem in 1 year) / year]</i>	<i>Fraction of Total Risk</i>	<i>Cumulative Fraction of Total Risk</i>	<i>Contributing Conditions</i>
1 – 2	4.57E-04	174.95	7.99E-02	2.97E-01	0.297	Groundwater, Level = ULT / WLT, ULT Lateral
4 – 1c	5.84E-05	1096.01	6.11E-02	2.27E-01	0.524	Local Landslide or Seismic Damage 1, Level = Current / Low, Liquids
4 – 1	5.93E-05	539.60	3.18E-02	1.18E-01	0.643	Local Landslide or Seismic Damage 1, Solids
2 – 1	4.00E-05	683.01	2.73E-02	1.02E-01	0.744	Groundwater, Level = High, WLT Lateral
1 – 3	3.12E-02	0.59	1.85E-02	6.88E-02	0.813	Groundwater, Level = Current, ULT Lateral
3 – 4	2.51E-04	69.66	1.73E-02	6.44E-02	0.877	Overflow, Level = ULT / WLT, > 9 inches in 14 days
1 – 4	3.33E-02	0.35	1.17E-02	4.36E-02	0.921	Groundwater, ULT-KRS
1 – 1	4.00E-05	290.64	1.16E-02	4.32E-02	0.964	Groundwater, Level = High, ULT Lateral
3 – 3	2.01E-05	294.57	5.44E-03	2.02E-02	0.985	Overflow, Level = High, Surface Disturbed, > 1 inch in 14 days
4 – 1b	8.13E-07	2283.36	1.77E-03	6.58E-03	0.991	Local Landslide or Seismic Damage 1, Level = WLT / ULT, Liquids
4 – 3c	8.65E-07	1187.35	1.17E-03	4.35E-03	0.995	Seismic Damage 2, Level = Current / Low, Liquids
4 – 1a	7.12E-08	4749.39	3.23E-04	1.20E-03	0.997	Local Landslide or Seismic Damage 1, Level = High, Liquids
4 – 3	8.79E-07	361.82	3.21E-04	1.19E-03	0.998	Seismic Damage 2, Solids
3 – 5	9.93E-07	171.28	1.67E-04	6.22E-04	0.999	Overflow, Level = ULT / WLT, Wind or Tornado, > 9 inches in 14 days
3 – 7	4.79E-06	34.78	1.49E-04	5.56E-04	0.999	Overflow, Level = Current / Low, > 25 inches in 14 days
4 – 2c	6.89E-08	1096.01	7.92E-05	2.95E-04	0.999	Gully Erosion, Level = Current / Low, Liquids
3 – 6	9.75E-07	69.46	6.23E-05	2.32E-04	1.000	Overflow, Level = ULT / WLT, Surface Disturbed, > 9 inches in 14 days
4 – 2	7.00E-08	539.60	3.81E-05	1.42E-04	1.000	Gully Erosion, Solids
4 – 3b	1.20E-08	2740.03	3.75E-05	1.40E-04	1.000	Seismic Damage 2, Level = WLT / ULT, Liquids
4 – 4c	4.95E-09	2557.37	1.35E-05	5.00E-05	1.000	Global Landslide, Level = Current / Low, Liquids
4 – 3a	1.05E-09	5662.74	6.79E-06	2.53E-05	1.000	Seismic Damage 2, Level = High, Liquids
5 – 1	3.69E-07	18.18	6.66E-06	2.48E-05	1.000	Aircraft crash or meteorite
3 – 2	1.97E-07	14.38	2.79E-06	1.04E-05	1.000	Overflow, Level = High, Wind or Tornado
4 – 2b	9.58E-10	2283.36	2.30E-06	8.54E-06	1.000	Gully Erosion, Level = WLT / ULT, Liquids
3 – 1	1.99E-08	28.60	6.32E-07	2.35E-06	1.000	Overflow, Level = High, 24- or 48-Hour Storm

Scenario	Mean Frequency (event / year)	Mean Dose (mrem in 1 year)	Mean Frequency x Dose [(mrem in 1 year) / year]	Fraction of Total Risk	Cumulative Fraction of Total Risk	Contributing Conditions
3 – 9	2.07E-08	34.78	5.57E-07	2.07E-06	1.000	Overflow, Level = Current / Low, Surface Disturbed, > 25 inches in 14 days
3 – 8	1.93E-08	34.78	5.33E-07	1.98E-06	1.000	Overflow, Level = Current / Low, Wind or Tornado, > 25 inches in 14 days
4 – 4b	6.89E-11	6028.08	4.41E-07	1.64E-06	1.000	Global Landslide, Level = WLT / ULT, Liquids
4 – 2a	8.39E-11	4749.39	4.18E-07	1.56E-06	1.000	Gully Erosion, Level = High, Liquids
4 – 4	5.03E-09	24.95	1.17E-07	4.34E-07	1.000	Global Landslide, Solids
4 – 4a	6.03E-12	9772.79	6.26E-08	2.33E-07	1.000	Global Landslide, Level = High, Liquids

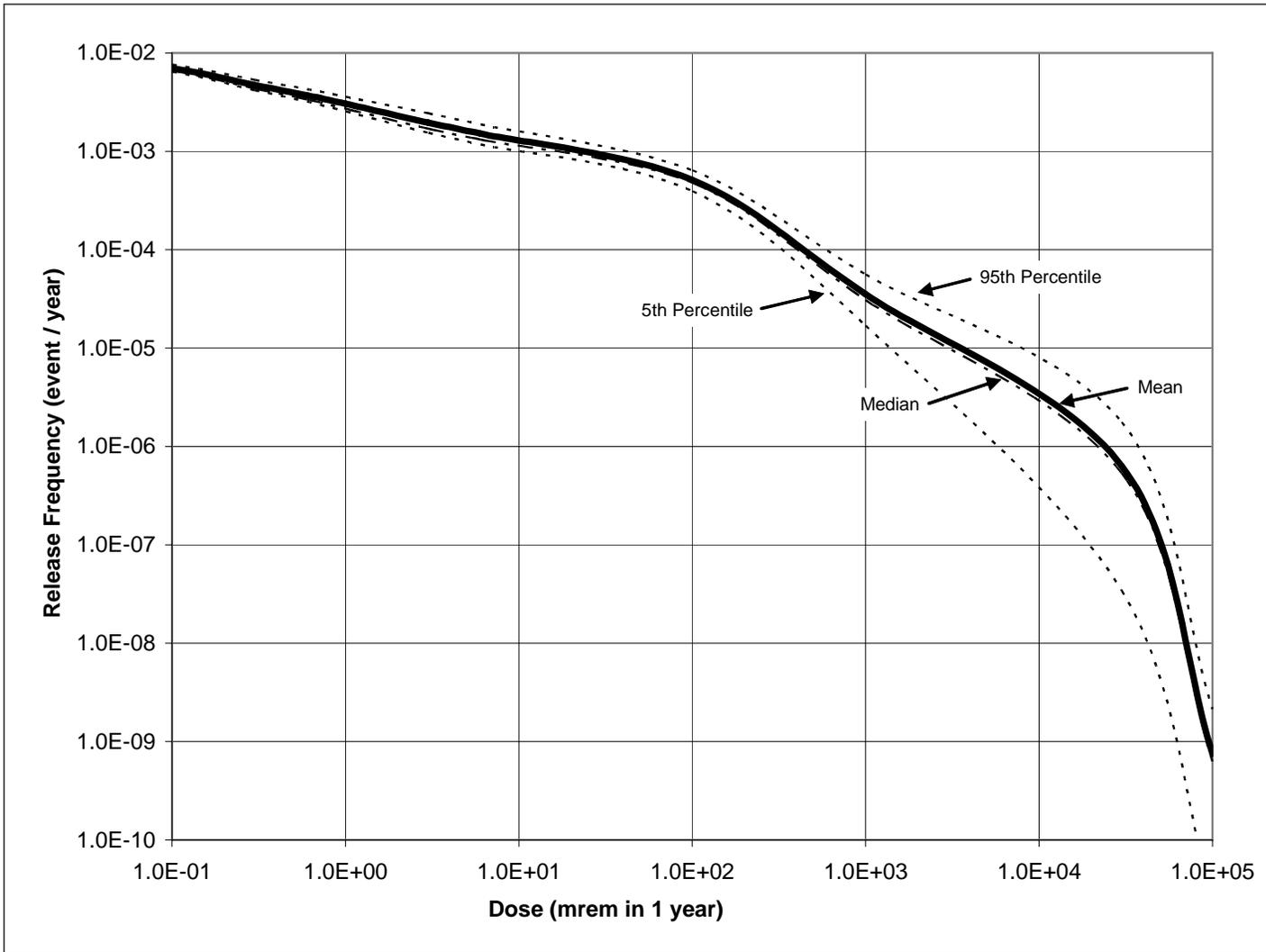


Figure P-1 SDA Risk Curves, Exceedance Frequency Format

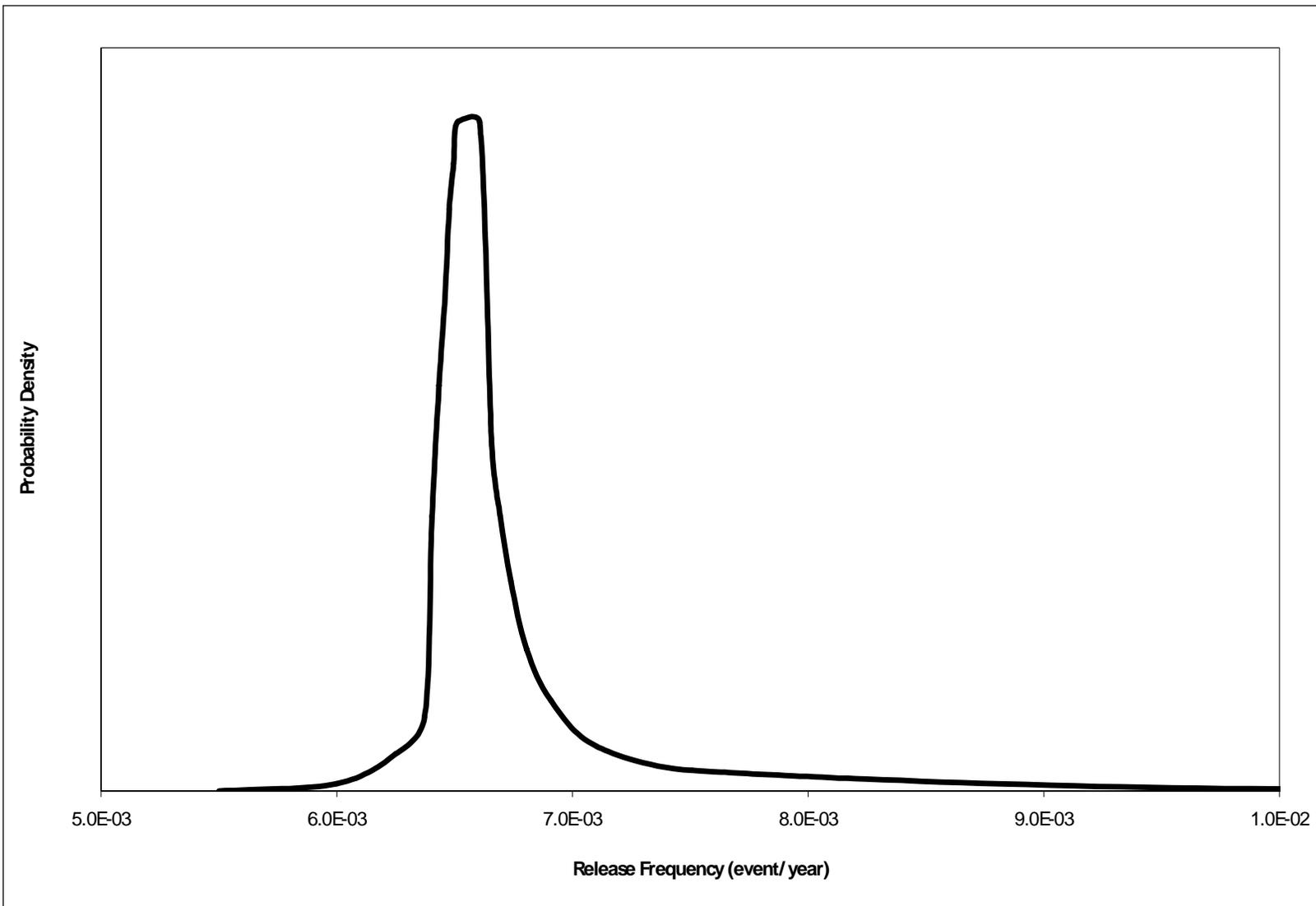


Figure P-2 Release Frequency for Exceeding a Dose of 0.1 mrem in 1 Year, Probability Density Format

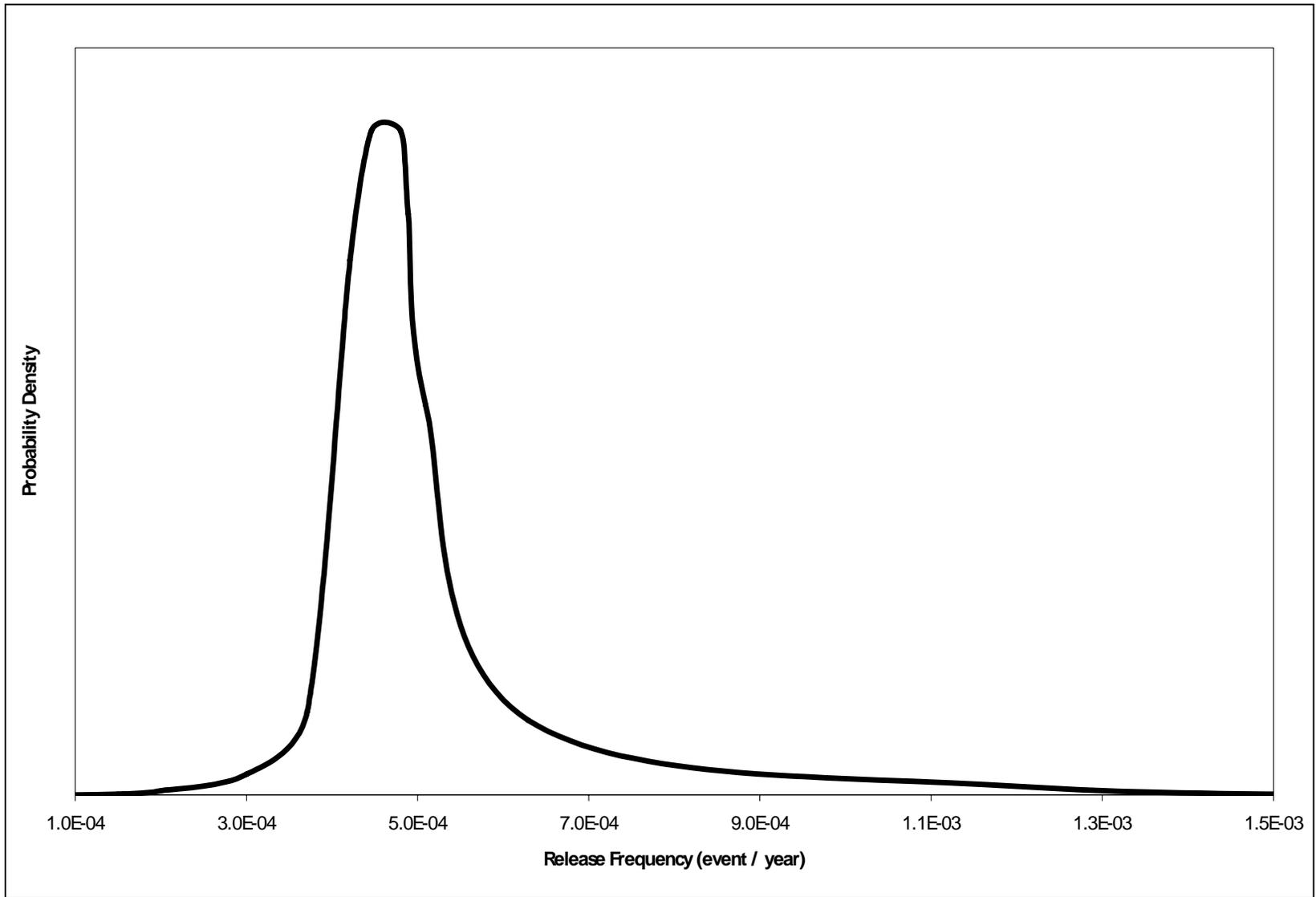


Figure P-3 Release Frequency for Exceeding a Dose of 100 mrem in 1 Year, Probability Density Format

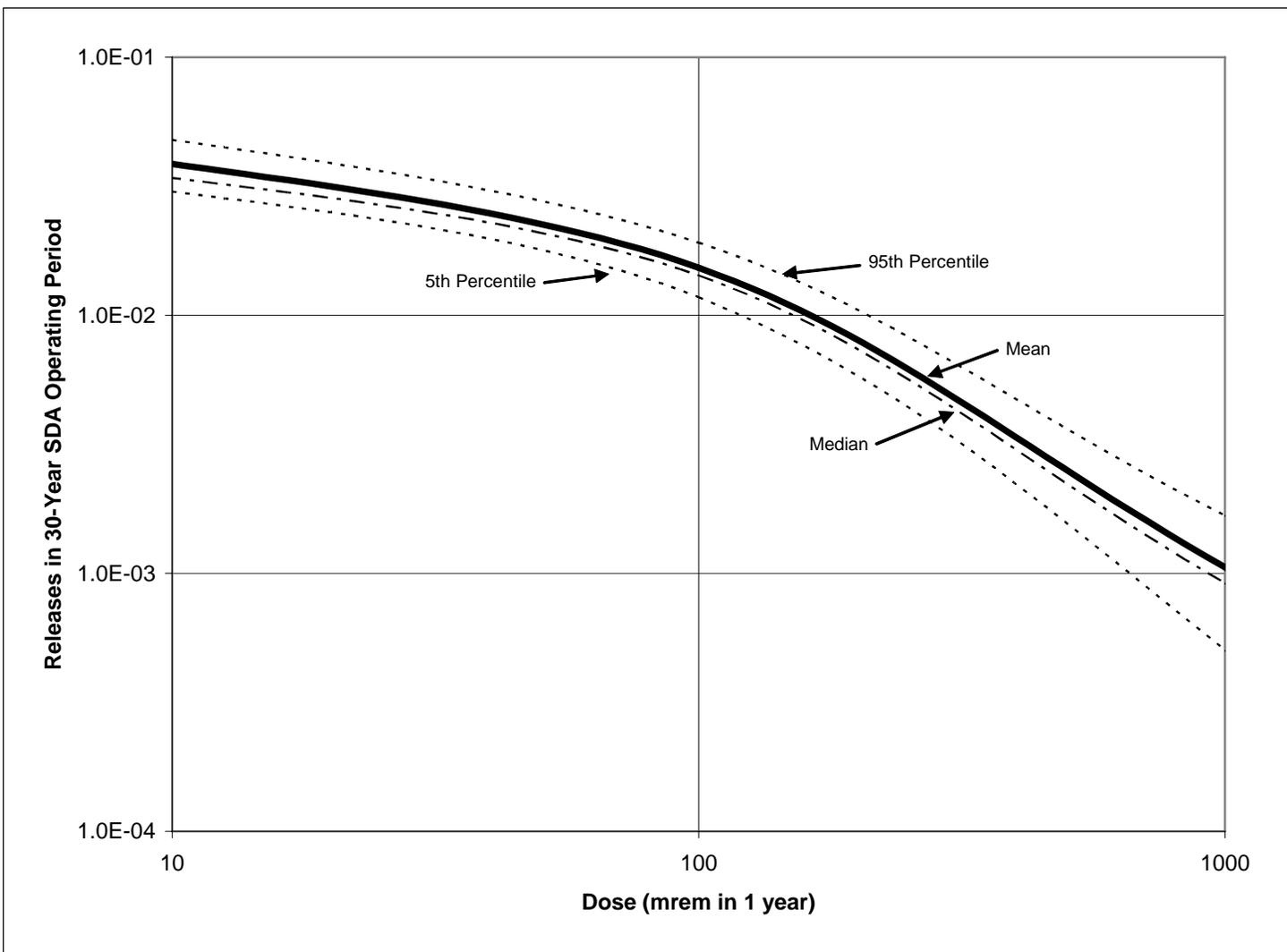


Figure P-4 SDA Risk Curves, 30-Year Operation Period Exceedance Format (Expanded Scale)

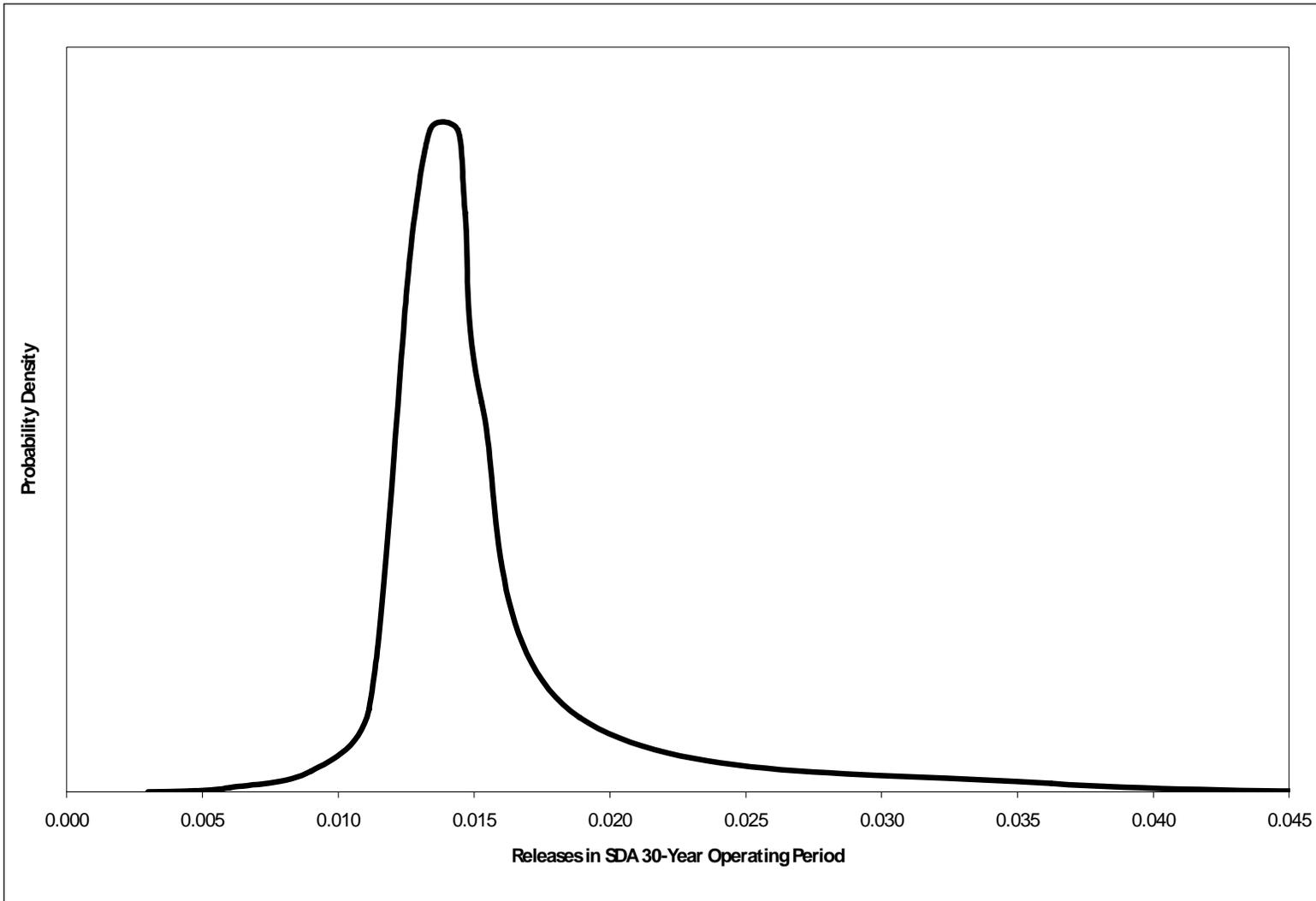


Figure P-5 Releases in SDA 30-Year Operation Period with Doses that Exceed 100 mrem in 1 Year